Patent Application

of

January Kister, James Jaquette and Steve Fahrner

for

Multipath Interconnect with Meandering Contact Cantilevers

FIELD OF INVENTION

The present invention relates to interconnect assemblies for repetitively establishing conductive contact between opposing contact arrays. Particularly, the present invention relates to interconnect assemblies having a number of arrayed interconnect stages including meandering cantilever contacts combined with a planar carrier structure.

BACKGROUND OF INVENTION

Demand for ever decreasing chip fabrication costs forces the industry to develop new solutions for inexpensive and reliable chip testing devices. A central component for repetitively contacting contact arrays of tested circuit

chips is an interconnect assembly that is placed adjacent a test apparatus contact array that has contact pitch corresponding to the tested chips' carrier (package) contact pitch. During packaged chip testing, a package is brought with its contact array into contact with the interconnect assembly such that an independent conductive contact is established between each of the package's contacts and the corresponding contact of the test apparatus.

A first important aspect for reliable performance of a test apparatus is the interconnect assembly's ability to establish conductive contact with constant minimum electrical resistance to the tested chip over a maximum number of test cycles. For that purpose, multiple conductive paths are desirable between each pair of opposing contacts to level contact resistance fluctuations and to reduce the total transmission resistance of the interconnect stage.

In addition, eventual oxide and contaminant layers need to be removed by a scratching movement of the interconnect assembly's contact tips along the test contact surfaces. In addition, each of the assembly's interconnect stages needs to provide a maximum contacting flexibility to resiliently compensate for dimensional discrepancies of the tested contacts. The present invention addresses these needs.

A second aspect for reliable performance is minimum fatigue of the involved parts such that a constant contacting force is maintained for a maximum number of test cycles. Prone

to fatigue in common interconnect assemblies are peak stress regions of repetitively elastically deformed interconnect members. Also commonly affected by fatigue failure is the connecting interface of the conductive structure with the non conductive carrier structure, which tends to delaminate as a result of repetitive high peak load changes in the interface. The present invention addresses these issues.

For a cost effective and reliable fabrication of interconnect assemblies there exists a need for a interconnect configuration that requires a minimum number of involved fabrication steps and individual components. Fabrication steps are preferably performed along a single axis. Assembling operations are preferably avoided. The present invention addresses this need.

SUMMARY OF THE INVENTION

An interconnect assembly includes a number of interconnect stages combined in a preferably planar carrier structure. Each interconnect stage includes at least two contact sets having an upwards pointing cantilever contact and a downwards pointing cantilever contact. The cantilever contacts are attached with a common base onto framing elements of the carrier structure. The framing elements are arranged around openings in the carrier structure such that the downward pointing cantilever contacts may reach through the carrier structure. Each contact set defines an independent conductive path between a single pair of opposing chip and test apparatus contacts such that

multiple conductive paths are available for each interconnect stage to transmit electrical pulses and/or signals with increased reliability and reduced electrical resistance compared to prior art single path interconnect stages.

The cantilever contacts have a meandering contour and are either combined at their tips in symmetrical pairs or are free pivoting with released tips. The meandering contour provides a maximum deflectable cantilever length within an available footprint contributing to a maximum flexibility of each interconnect stage.

BRIEF DESCRIPTION OF THE FIGURES

The file of this patent contains Figures 12 - 18 executed in color. Copies of this patent with color drawings will be provided by the Patent and Trademark Office upon request and payment of the necessary fee.

Fig. 1 is a perspective view of a portion of an interconnect assembly in accordance with a first embodiment of the present invention.

Fig. 2 illustrates a top view of the assembly portion of **Fig. 1**.

Fig. 3 depicts a bottom view of the assembly portion of **Fig. 1**.

Fig. 4 shows a perspective view of an individual interconnect stage of the assembly portion of **Fig. 1.**

Fig. 5 is a side view of the interconnect stage of **Fig. 4.**

Fig. 6 depicts a top view of a contact set of the interconnect stage of **Fig. 4.**

Fig. 7 illustrates a top view of a portion of the contact set of **Fig. 6** including a single meander cantilever in flattened condition.

Fig. 8 depicts a modified meander cantilever in flattened condition.

Fig. 9 depicts a modified contact set including an upward and a downward bent meander cantilever of **Fig. 8.**

Fig. 10 is a top perspective view of a interconnect stage in accordance with a second embodiment of the present invention including a number of modified contact sets of **Fig. 9.**

Fig. 11 is a bottom view of the interconnect stage of **Fig. 10.**

Fig. 12 shows a comparative stress analysis of the meander cantilever of **Fig. 7** having a contact tip beam connected with an adjacent tip beam of a mirrored representation of the meander cantilever of **Fig. 7.**

Fig. 13 shows a comparative displacement analysis of the meander cantilever of **Fig. 7** having a contact tip beam connected with an adjacent tip beam of a mirrored representation of the meander cantilever of **Fig. 7**.

Fig. 14 shows a comparative stress analysis of the meander cantilever of **Fig. 7** having a released tip beam.

Fig. 15 shows a comparative displacement analysis of the meander cantilever of **Fig. 7** having a released tip beam.

Fig. 16 shows a comparative stress analysis of the meander cantilever of **Fig. 8** having a released tip beam.

Fig. 17 shows a comparative displacement analysis of the meander cantilever of **Fig. 8** having a released tip beam.

Fig. 18 is a scaled side view of the comparative displacement analysis of **Fig. 17**. Displacement is depicted off a vertical.

DETAILED DESCRIPTION

According to **Figs. 1-3**, an interconnect assembly **1** may include a carrier structure **2** made of a rigid, non

conductive material such as PCB. The carrier structure **2** holds a number of interconnect stages **3** that are two dimensionally arrayed with pitches **PX** and **PY**. The pitches **PX**, **PY** are defined in conjunction with pitches of a tested circuit chip contacts as is well known in the art.

Preferably each but at least one of the interconnect stages **3** features at least two but preferably four upwards pointing meandering cantilever contacts **31** and at least two but preferably four downwards pointing meandering cantilever contacts **32**. The interconnect stages **3** are attached at the top face **22** of the carrying structure **2**. At this point it is noted that the terms "top, bottom, upwards, downwards" are introduced for the sole purpose of establishing relative directional relations between individual components rather than spatial position or orientations.

Preferably each but at least one of the interconnect stages **3** is configured for establishing multiple paths conductive contact between opposing contacts **8, 9** (see **Fig. 5**). The conductive contacts **8, 9** are preferably arrayed in a separate well known grid array. The contacts **8, 9** may have a spherical shape well known for so called ball grid arrays. One of the opposing contact arrays may be part of a tested circuit chip's package and the other of the opposing contact arrays may be part of a testing apparatus having its contact pitch adjusted to that of the tested circuit chip's package.

The interconnect stages **3** are positioned with a certain clearance **CL** to each other to provide electric insulation

between adjacent interconnect stages **3**. Thus, stage extensions **DX, DY** are the remainder of the Pitches **PX, PY** reduced by clearances **CL** between all adjacent interconnect stages **3.**

The interconnect stages **3** are preferably shaped directly on the carrier structure by well known processes for fabrication millimeter scale and sub millimeter scale structures. Such processes may include electro deposition, electro plating, deep trench etching and the like. For these preferred fabrication cases, the stage extensions **DX, DY** define the overall real estate within which the meandering cantilevers **31, 32** are fabricated. The geometric shape of the real estate corresponds thereby to the array pattern of the tested chip's package and is preferably square but may have any geometrical shape as may be well appreciated by anyone skilled in the art.

The cantilever contacts **31, 32, 41, 42** (see also **Figs. 8-11**) are preferably deposited in a planar shape on top of an initially solid carrier structure **2, 5** (see also Figs. **8-11**). In a following operation, openings of the carrier structure **2, 5** are fabricated in well known fashion and a bendable portion of the finally contoured cantilever contacts **31, 32, 41, 42** are partially released from the carrier structure **2**. In a final fabrication step, the bendable portions including the cantilever contacts **31, 32, 41, 42** are bent along bending axes **308, 3082, 4082** (see also **Figs. 5-9**). As shown in **Fig. 3**, openings are defined in the carrier structure **2** in between framing elements **21.**

As depicted in **Fig. 4**, two upwards pointing cantilevers **31** are combined with two downwards pointing cantilever **32** in a contact set **30**. Each of the cantilevers **31**, **32** has a base **301** that is attached to the carrier structure **2**. In the fabrication case described in the above paragraph, the base **301** is the non released portion of the initially planar deposited conductive structure. From the base **301** extend base beams **302** towards a contact tip **307**. At the end of the base beam **302** that is close to the contact tip **307** is a reverting bow **303** from which a reverting beam **304** protrudes away from the contact tip **307**. At the end of the reverting beam **304** that is distal to the contact tip **307** is a forward bow **305** from which again a tip beam **306** is extending towards and terminating in the contact tip **307**. The base **301** is preferably the only non deflecting portion of the cantilevers **31, 32**. All other components **302 - 307** deflect as a result of a contact **8, 9** being forced against the contact tips **307**.

In the contact set **30**, the two cantilevers **31** and the cantilevers **32** are mirrored representations of each other and combined along a beam connect **3062**, which is preferably placed at the central end of the tip beams **306**. The beam connect **3062** may be optionally employed for mutual lateral support of adjacent pairs of cantilevers **31, 32** with their respective bases **301** being connected as well for including all cantilevers **31, 32** for electrical current propagation.

After preferred initial planar fabrication and partial release of the deflectable portion, a bending operation may be employed to reorient at least one of the components **302 - 307** in direction parallel to the contacting axis **CA**. The

bending operation is preferably applied along a bending axis **308** in closest proximity to the base **301**. In that fashion and as illustrated in **Fig. 5**, a maximum tip height **TH** may be obtained for a given bending angle **BA**, where a bend axis distance **BD** is brought to a maximum. Since small bending angles **BA** are desired to minimize the risk of excessive plastic deformation in the bending region, the bending axis **308** is positioned preferably at a maximum bending axis distance **BD**.

The contacting axis **CA** is a geometric element introduced for the purpose of ease of understanding and generally describing the operational geometric conditions that exist for interconnect assemblies **3, 4**. The preferred mode of interconnect assembly's **1** operation is with contacts **8, 9** approaching substantially perpendicular and in a centered fashion with respect to the planar layout of each interconnect stage **3** and the carrier structure **2** respectively reflected by the contacting axis **CA**. The scope of the invention includes embodiments in which the one or both contacts **8, 9** approach the interconnect stages **3, 4** other than perpendicular as long as they follow the breath of the teachings presented above and below as may be well appreciated by anyone skilled in the art.

The bending axes **308, 3082, 408, 4082** are introduced above and in the below as simplified descriptions of the angular deformation process induced to the cantilevers **31, 32, 41, 42** to spatially reorient their released portions. The angular deformation process may include any well known plastic forming steps including mechanical and/or thermal deformation. The bent region in the vicinity of the

bending axes may have radiuses and other features commonly affiliated with these plastic forming steps. The bending axes **308, 3082, 408, 4082** may be interpreted as an axis around which to the majority of the released cantilever portion is substantially rotated during the plastic forming step(s). The scope of the invention includes embodiments, in which the released cantilever portions are three dimensionally shaped with multiple plastic forming operations. The scope of the invention includes also embodiments, in which the released cantilever portions are three dimensionally fabricated with well known 3D shaping operations and without plastic forming operations.

As illustrated in **Fig. 6** and **7**, each of the cantilevers **31, 32** is fabricated within a triangular footprint **FP** having a center corner coinciding with the contacting axis **CA**, a symmetry boundary **SB** and a distal portion including a distal corner **DC** most distal to the contacting axis **CA**. The most distant corner **DC** is at the distal end of the longest boundary line of the foot print **FP**. In the case of squarely arrayed test contacts, the overall layout of the interconnect stages **3** is also in a square fashion and the maximum available real estate is consequently square as well. Where in that case a total of eight cantilevers **31, 32** are employed per interconnect stage **3**, the footprint **FP** is substantially a rectangular triangle with its hypotenuse **HP** extending as the longest boundary line along a diagonal between opposing edges of the stage's **3** real estate. In that case, the center corner and the distant corner **DC** are the endpoints of the hypotenuse **HP**. As is clear to anyone skilled in the art, the footprint **FP** may be shaped in conjunction with any test contact array pattern and its

derived optimized real estate as well as any number of identical and/or non identical cantilevers **31, 32, 41, 42** employed within an interconnect stage **3**.

The bases **301, 401** (see also **Figs. 8-11**) are placed within the distal portion of the footprint **FP** and substantially coplanar with said footprint as the non release portion of the cantilevers **31, 32, 41, 42**. In the case of the exemplary interconnect stage **3** with pair wise connected mirrored cantilever representations, the beam connect **3062** substantially coincides with the symmetry boundary **SB** of the footprint **FP**. The scope of the invention includes embodiments, in which combined cantilevers are other than mirrored representations of each other as may be well appreciated by anyone skilled in the art.

Also in the case of pair wise connected mirrored cantilever representations, the bending axes **308** of connected pairs of cantilevers **31, 32** are preferably collinear to avoid internal stress in the conductive structure as a potential result of the bending operation as may be well appreciated by anyone skilled in the art. In such case, a maximum bend axis distance **BD** is limited by its orientation along the symmetry boundary **SB**.

In the case of not connected cantilevers **31, 32** a modified bending axis **3082** may be oriented such that it is middle perpendicular to the contact tip **307** as shown in **Fig. 7**. As a result, the bend axis distance **BD** may be increased beyond the length of the symmetry boundary **SB**, which in turn reduces the bending angle **BA** for a defined tip height **TH**.

Comparative stress and displacement analyses of the cantilevers **31, 32** connected via beam connect **3062** is depicted in **Figs. 12, 13.** For given material properties, a given tip contact force, and a given contour height, the cantilevers **31, 32** may experience a reference stress of close to 100% along an inner radius **3053** of the forward bow **305.** Deflection of the contact tip **307** is about 109% of a reference displacement of 0.1. Stress gradients are at highest levels between inner radii **3031, 3051** and their respective outer radii **3033, 3053** as well as around the socket radius **3021.**

Results of tested experimental interconnect stages similar to stage **3** with pair wise connected cantilevers **31, 32** were fabricated of Nickel Manganese for a pitch **PX, PY** of about 1.27 mm. The testing revealed an average contact force of 25 Grams at a total average deflection of both cantilevers **31, 32** of about 0.012″ during 100,000 number of testing cycles.

Comparative stress and displacement analyses of freely suspended cantilevers **31, 32** are depicted in **Figs. 14, 15.** For the same analysis conditions as in **Figs. 12, 13**, the cantilevers **31, 32** may experience a reference stress of similarly close to 100% along an inner radius **3053** of the forward bow **305.** Deflection of the contact tip **307** is about 127% of a reference displacement 0.1. Bending axis **308** is applied in analyses of **Figs. 12 - 14.** For a given cantilever contour, the displacement of freely suspended cantilevers **31, 32, 41, 42** is about 20% larger than tip

connected cantilevers **31, 32, 41, 42** with similar stress distributions for both conditions.

The integration of at least two contact sets **30** introduces at least two completely separate conductive paths between the contacts **8, 9** within a single interconnect stage **3.** Each contact set **30** established an independent conductive path across base connect **309, 409** (see also **Fig. 9**). As shown in **Fig. 4,** the absence of the base connect **309** establishes an insulation gap **IG** between adjacent bases **301** of separate contact sets **30.** In case of beam connected cantilevers **31, 32,** their respective bases **301** may be also conductively connected to provide current flow along both paired cantilevers **31, 32.**

With increasing number of independent contacting paths the overall transmission resistance between opposing contacts **8, 9** becomes lower in accordance with the well known physical law that the reciprocal total resistance equals the sum of each of the conductive paths' reciprocal path resistance. In addition, multiple contacting path average fluctuations in the contact resistance between the individual contact tips **307** and their respective contacts **8, 9.** The average overall contacting resistance of the tested experimental interconnect stages fluctuated of about 5% during above number of testing cycles.

According to **Figs. 8 - 11,** a number of modifications may be introduced to cantilevers **31, 32,** which are all together depicted in a modified cantilever **41/42.** Teachings presented for cantilevers **31, 32** may be applied to the modified cantilever **41/42** and vice versa. The

configurations and modifications of cantilevers **31, 32, 41, 42** may be optionally combined in fashion and number as appreciated by anyone skilled in the art.

The modified cantilever **41/42** corresponds in application substantially to cantilevers **31** and **32**. A modified base **401** has a base extension **4015** extending along the base beam **402** towards the contact tip **407.** In that fashion, the interface boundaries between the base **401** and the carrier structure **5** may be extended beyond a bending axis support **54** (see **Fig. 11**) reducing the risk of eventual well known delamination due to peak stresses in the interface boundaries. The base **401** has a reduced lateral extension giving way to an enlarged forward bow **405.** The bending axis **4082** is middle perpendicular to the contact tip **407.** The base beam **402** propagates towards the contact tip **407** with its lateral contours substantially symmetric to a base beam symmetry axis **4029**, which in turn preferably coincides with the contact tip **407.** In that fashion, the base beam **402** is substantially free of torque and sheer stress. As an additional favorable result, stress distributions along the bending axis **4082** are substantially equal and substantially free of stress gradients in the proximity of the socket radii **4021.**

The base beam **402** is exposed to a major degree to a bending momentum resulting from the contacting force acting on the contacting tip **407.** To a minor degree, the base beam **402** is also exposed to an opposite momentum applied at its end that is close to the contact tip **407.** This is well visible in **Fig. 18** depicting the scaled side view of a comparative displacement analysis computed with the same analysis

conditions as in **Figs. 12, 13.** An optimized base beam **402** has therefore side contours that are oriented in a slight outward offset to the contact tip **407.** The base beam **402** may be extended such that sufficient area is available within the footprint **FP** for the reverting bow **403** adjacent the tip beam **406.**

Radial stress gradient in the reverting bow **403** may be reduced by reducing the discrepancy between inner radius **4031** and the outer radius **4033.** The same applies even more importantly to the forward bow **405** and its inner and outer radii **4051** and **4053.** This is caused by the larger distance of the forward bow **405** to the contact tip **407** such that the torque experienced in the forward bow **405** between tip beam **406** and reverting beam **404** is substantially larger than the torque experienced by reverting bow **403.** The meandering contour of the flexible cantilever portion advantageously utilizes the triangular foot print **FP** to provide the forward bow **405** with a maximum radius.

Reducing the lateral extension of the base **401** additionally increases the area available for the forward bow **405. Fig. 16** shows a comparative stress analysis computed for the cantilever **41/42** with the same analysis conditions as in **Figs. 12, 13.** The stress gradients in the bows **403, 405** are substantially reduced. The peak stress in the forward bow **405** is about 57% of the reverence maximum. In addition, the peak stress regions in the bows **403, 405** are in an offset to the contour boundaries which is a favorable condition for reducing fatigue cracking.

Reverting beam **304** is exposed to both bending and torsion. Bending momentums are active at both ends. On one side this is due to the resilience of the base beam **402** and the reverting bow **403**. On the other side this is due to a momentum resulting from the contact force via the tip beam **406** and the forward bow **405**. Torsion momentums apply in similar fashion. Both bending and torsion momentums counteract resulting in a pivoting of the reverting beam **404**, which is reflected in **Figs. 17, 18** as a zero displacement. **Fig. 18** shows that the deformation resulting from the torsion is at relatively low levels compared to the bending deformation. Stress and displacement analyses of **Figs. 12- 18** are computed on planar reference objects. The displacement visible in **Fig. 18** is therefore a displacement off the vertical orientation.

The tip beam **406** is at least in the vicinity of the forward bow **405** symmetrically profiled with respect to the symmetry line **4069**, which coincides with the contact tip **407**. In addition, the width of the tip beam **406** preferably changes in proportion with the distance to the contact tip **407** irrespective of optional secondary meandering bends **4063, 4064** and optional offset tip beam portion **4065**.

The individual elements of the cantilevers **31, 32, 41, 42** are preferably fabricated in planar condition as shown in **Figs. 7, 8**. Separation of the individual elements is warranted by including minimum gaps between adjacent structures. As a result, the contacting tips **307, 407** are in a slight offset to the contacting axis **CA**. This offset increased during the bending operation. This tip offset may be advantageously utilized in combination with the

offset tip beam portion **4065** for an improved centering action of concurrently contacting cantilevers **41** and **42.** This may be of particular value where at least one of the contacts **8, 9** is spherically shaped.

A modified carrier structure **5** may feature separately configured base extension supports **53** for supporting the base extensions **4015.** In addition, the modified carrier structure **5** may feature cantilever releases **56** for a collision free deflection of the cantilevers **42.**

Contact set **30** preferably includes two combined cantilever pairs with a total of four cantilevers **31, 32.** The contact set **40** includes preferably two cantilevers **41, 42.** In both contact sets **30, 40** the downward oriented cantilevers **32, 42** are rotated representations of the upwards oriented cantilevers **31, 41** rotated around a boundary edge of the footprint **FP** and vice versa. The preferred boundary edge for rotating the rotated representations is the longest edge of the footprint **FP**, which in case of a rectangular footprint **FP** is the hypotenuse **HP.** The rotated representations are placed within the real estate, such that that their respective bases are immediately adjacent and conductively connected via the base connect **309, 409** (see also **Fig. 8**) and such that their respective contact tips **307, 407** are within a similar offset to said contacting axis **CA.**

Up- and downward cantilevers **31, 41** and **32, 42** are combined at their respective bases **301, 401** via the base connects **309, 409.** The interconnect **3** features two completely independent conductive paths and the interconnect **4**

features four completely independent conductive paths. The combination of cantilevers **31, 32** and **41, 42** as rotated representations of each other provides for a balanced contacting of contacts **8, 9** with a minimum of deviation momentums eventually forcing the contact tips **307, 407** laterally away from the contacting axis **CA**. As a result, the cantilevers **31, 32, 41, 42** may be shaped with reduced stiffness which is favorable for reducing an overall contact force of a tested chip having a large number of contacts **8**.

Cantilevers **41** are circumferentially arranged around the contacting axis **CA** preferably in mirrored configuration to minimize eventual external torque around the contacting axis **CA** resulting from the deflection of the cantilevers during impact of contacts **9**. Likewise, cantilevers **42** are circumferentially arranged around the contacting axis **CA** also preferably in mirrored configuration to minimize eventual external torque around the contacting axis resulting from the deflection of the cantilevers during impact of contact **8**. Regardless this preference, the scope of the invention is not limited to a particular arrangement of the cantilevers **31, 41, 32, 42** within an interconnect stage **3, 4** and within the breath of the teachings presented above.

The individual modifications taken together result in highly uniform stress distributions of the released portion of the cantilever **41, 42** including low stress peaks, shallow stress gradients and improved tip displacement. As depicted in **Figs. 16, 17, 18**, the overall peak stress is about 57% of the reference maximum and the displacement of

the contact tip **407** is about 164% of the reference displacement.

The scope of the invention includes embodiments in which contact sets **30, 40** are separately fabricated and combined with the carrier structures **2, 5** in a final operation.

The scope of the invention includes embodiments in which a cantilever contact **31, 41** may be utilized to establish contact between contact **8** and any other well known contact or conductive lead directly temporarily or permanently connected to base **301, 401.** Likewise, the scope of the invention includes embodiments in which a cantilever contact **32, 42** may be utilized to establish contact between contact **9** and any other well known contact or conductive lead directly temporarily or permanently connected to base **301, 401.**

The scope of the invention includes embodiments in which one ore both of contacts **31, 41** and **32, 42** are executed without reverting bow **303, 403,** reverting beam **304, 404,** forward bow **305, 405** and without tip beam **306, 406.** In such embodiments, the base beam **302, 402** extends to and terminates in the contact tip **307, 407.** Also in such embodiments, the beam connect **3062** connects mirrored representations of base beam **306, 406.**

Accordingly, the scope of the invention described in the above specification is set forth by the following claims and their legal equivalents: